

The Elusive Petroexoccipital Articulation

ISRAEL HERSHKOVITZ,^{1,2*} BRUCE LATIMER,^{1,3} OLIVIER DUTOIR,⁴
LYMAN M. JELLEMA,¹ SUSANNE WISH-BARATZ,²
CHRISTINE ROTHSCILD,⁵ AND BRUCE M. ROTHSCILD⁵

¹*The Cleveland Museum of Natural History, University Circle, Cleveland,
Ohio 44106-1767*

²*Department of Anatomy and Anthropology, Sackler Faculty of Medicine,
Tel Aviv University, Tel Aviv 69978, Israel*

³*Department of Anatomy, School of Medicine, Case Western Reserve
University, Cleveland, Ohio 44106-4921*

⁴*Université de la Méditerranée, Faculté de Médecine de Marseille, 13385
Marseille Cedex 5, France*

⁵*Arthritis Center of Northeast Ohio and Northeastern Ohio Universities
College of Medicine, Youngstown, Ohio 44512*

KEY WORDS age identification; skull base; jugular synchondrosis

ABSTRACT In the present study, 1,869 skulls from the Hamann-Todd Collection were examined (macroscopically and by radiographs) for closure of the petroexoccipital articulation (jugular synchondrosis). The results demonstrated that the petroexoccipital articulation underwent closure between 20 and 50 years of age in most of the human skulls evaluated. Approximately 7–10% of the human skulls underwent complete union of the petroexoccipital articulation before 20 years of age. In 5–9% of the population, the joint remained completely open. After 50 years of age, there was no increase in the frequency of individuals with complete closure. The frequency of “partial closure” was similar (4–8%) for all age groups (20–25, 30–35, 40–45, 50–55, 60–65, and 70+), excluding the 30–35 year old group (17.5%). The time interval necessary for closure to occur appeared to be very short. No significant differences in closure rates due to ethnic origin, gender, or laterality were noted. The utility of the petroexoccipital articulation as an age estimator is discussed. *Am J Phys Anthropol* 103:365–373, 1997.

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Although much attention has been focused on the cranial base and its growth in both anatomical and evolutionary contexts, our knowledge of the growth pattern at the petroexoccipital articulation (i.e., jugular synchondrosis) is meager. This is surprising considering the potential of this region as an aging criterion for both forensic and paleodemographic studies (Maat and Mastwijk, 1995) and its plausible utility in understanding cranial base growth patterns.

In the absence of any report in the scientific literature, anatomical textbooks are the sole source of information on the petroexoccipital articulation, and, even there, it is briefly mentioned. The few textbooks (e.g., Gray's Anatomy) that refer to it make gener-

alized statements, e.g., “. . . Laterally, the jugular process presents a rough quadrilateral or triangular area, which is joined to the jugular surface of the temporal bone by a growth plate of cartilage; about the age of 25, this plate begins to ossify” (Williams and Warwick, 1980, p. 322). When the development of the occipital bone is discussed in human osteological textbooks, the fusion (synostosis) between the occipital and sphe-

Contract grant sponsor: The Smithsonian Institution Natural History Museum.

*Correspondence to: I. HersHKovitz, Department of Anatomy and Anthropology, Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv 69978, Israel. E-mail: anatom2@post.tau.ac.il

Received 10 January 1996; revised 11 February 1997; accepted 21 April 1997.

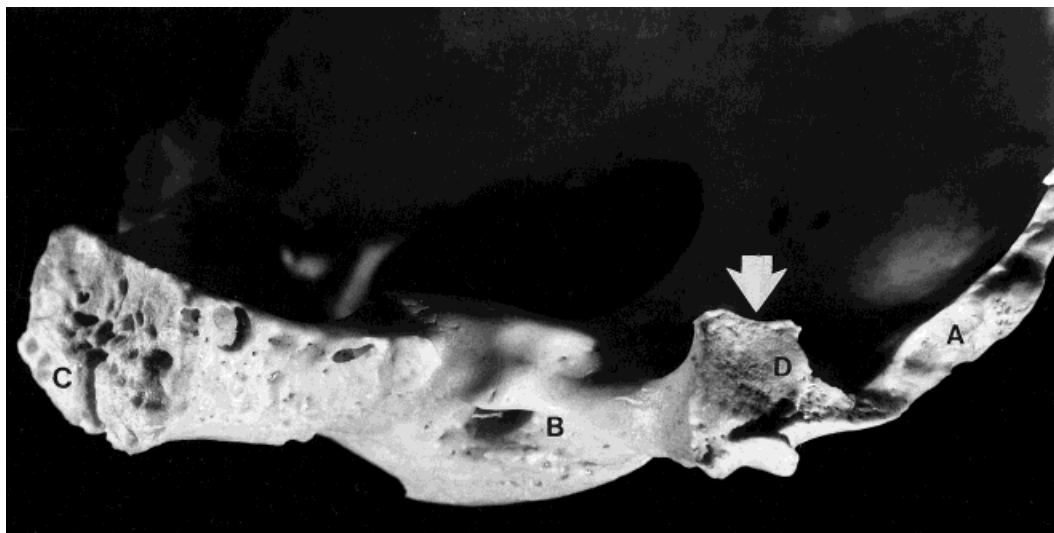


Fig. 1. Anterolateral view of the occipital base. Note the quadrangular shape of the articular surface of the jugular process (D). Also shown are the occipitomastoid suture (A), hypoglossal canal (B), articular surface with sphenoid, and sphenoccipital articulation (C).

noid bones (across the sphenoccipital synchondrosis) is often the only articulation mentioned (see, e.g., White, 1991). For no obvious reason, the study of the petroexoccipital articulation has evaded the interest of investigators, hence our title: "The Elusive Petroexoccipital Articulation."

The aims of the present study are to test (with a large data set) the well-accepted notion that the petroexoccipital articulation is ossified by the age of 25 years, to quantify any possible unification patterns of this articulation, and to examine the utility of using this region for forensic (aging) and evolutionary studies.

MATERIALS AND METHODS

This study is based on osteological changes at the petroexoccipital articulation, i.e., the ossification process of the jugular growth plate. The jugular process of the occipital bone is quadrilateral in shape and extends laterally from the posterior half of the occipital condyle (Fig. 1). It is excavated anteriorly by the jugular notch of the petrous part of the temporal bone, which, in the articulated skull, forms the posterior part of the jugular foramen. The inferior surface of the jugular process is rough and gives attachment to the rectus capitis lateralis muscle and the lat-

eral atlantooccipital ligament. The superior surface is grooved by the terminal part of the transverse sinus. Laterally, the jugular process presents a rough quadrilateral area that is joined to the jugular surface of the temporal bone (Fig. 2) by a plate of cartilage at the jugular synchondrosis (Williams and Warwick, 1980). According to Cunningham's textbook (Brash and Jamieson, 1937), "The jugular process is the homologue of the transverse process of the vertebra (p. 159)."

The present study was carried out in three stages. In the first stage, 196 skulls of known age (48 adult white males, 48 adult black males, 48 adult white females, 48 adult black females, and 24 adolescents) were used for preliminary analysis. All skulls were from the Hamann-Todd Osteological Collection, Cleveland Museum of Natural History. The skulls were divided into seven age groups (16–19, 20–24, 25–34, 35–44, 45–54, 55–64, and 65+) in accordance with their stated age. Because the skulls had been previously sectioned along the midsagittal plane, it was possible to observe the joint from both the internal and the external aspects (the latter via the jugular foramen).

The closure status of each petroexoccipital articulation (Fig. 3) was evaluated as follows: 1) open, no evidence of closure; 2)



Fig. 2. Posteroinferior view of the articular surface at the left petrous bone. The articular flat surface (M), which marks the inferior end of the occipitomastoid suture (A) is quadrilateral in shape. Also shown are the mastoid process (B), mandibular fossa (C), and carotid canal (D).

partial closure, some closure evident (up to 50% of the articulation area; synchondrosis); 3) significant closure, more than 50% of the articulation (synchondrosis) had fused; and 4) complete obliteration.

In the second stage, the validity of our ratings were examined by performing an equivalent set of 50 radiographs and CT scans (Figs. 4–10). The results were also checked for laterality, gender, and ethnicity effect (χ^2 test). The inter- and intraobserver errors (based on a random sample of 35 skulls) were estimated by using Kendall rank correlation coefficient and nested analysis of variance (Sokal and Rohlf, 1995).

In the third and final stage, the status of the petroexoccipital articulation was rated in all skulls, regardless of gender and ethnic origin, that fell into the following age cate-

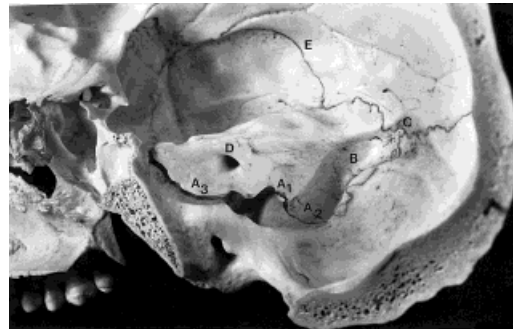


Fig. 3. Right endocranial cavity. Note the three different areas of articulation of the petrous bone with the occipital bone: A₁, petroexoccipital articulation (known as "jugular synchondrosis"); A₂, petrosupraoccipital articulation (part of the occipitomastoid suture); A₃, petrobasioccipital articulation. The petroexoccipital articulation (A₁) is still open. Other structures shown are the sigmoid sinus (B), asterion (C), internal acoustic meatus (D), and parietotemporal (squamosal) suture (E).

ries: 20–25 (145 skulls), 30–35 (245 skulls), 40–45 (471 skulls), 50–55 (436 skulls), 60–65 (287 skulls), and 70+ (285 skulls), and the aging effect on that articulation was examined.

RESULTS

The age distribution for the different closure stages of the petroexoccipital articulation appears in Table 1 and Figure 11. The statistical analysis appears in Table 2. Radiographic analysis reveals that the division between category 2 and category 3 is arbitrary (partially closure/significant closure). Therefore, in all subsequent analyses, those two categories were combined. The findings may be summarized as follows:

- 1) In most of the human skulls observed, the petroexoccipital articulation (jugular synchondrosis) underwent closure between 20 and 50 years of age;
- 2) in ca. 7–10% of the human skulls, complete union of the petroexoccipital articulation (jugular synchondrosis) occurred prior to 20 years of age;
- 3) in ca. 5–9% of individuals over 50 years of age, the joint remained completely open;
- 4) after 60 years of age, there was no increase in the frequency of individuals with complete closure of the jugular synchondrosis;

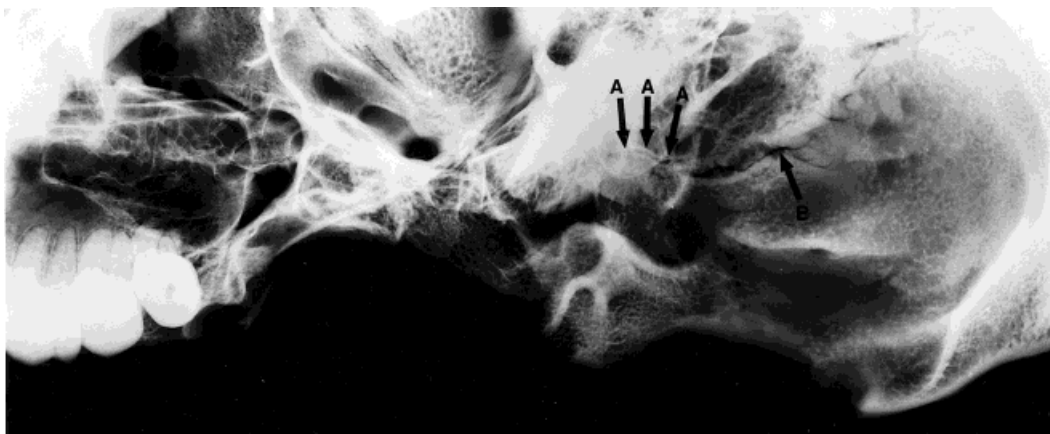


Fig. 4. Superolateral radiograph view of HTH 1228 (white male, 20 years of age) with the petroexoccipital articulation open (A). B, occipitomastoid suture.



Fig. 5. Superolateral radiograph view of HTH 741 (white male, 61 years of age) with the petroexoccipital articulation closed (A). B, occipitomastoid suture; C, asterion.

- 5) the frequency of "partial closure" was similar in all age groups (4–8%), except for the 30–35 year age group (17.5%);
- 6) no differences in closure rate pattern due to ethnic origin or gender were noted (Table 2);
- 7) no effect of laterality (right side vs. left side) was noted ($\chi^2 = 2.110$, $P = .3481$);
- 8) similar trends (to those described above) were noted when age was assessed by observing the jugular synchondrosis through the jugular foramen; and
- 9) inter- and intraobserver reliability was high for the three scoring methods (2 and 3 combined), indicating that the three-category scoring method was highly replicable. Kendall rank correlation (Tau corrected for ties) for the interobserver error was $r = 0.91$, and it was $r = 0.96$ for the intraobserver error. Nested analysis of

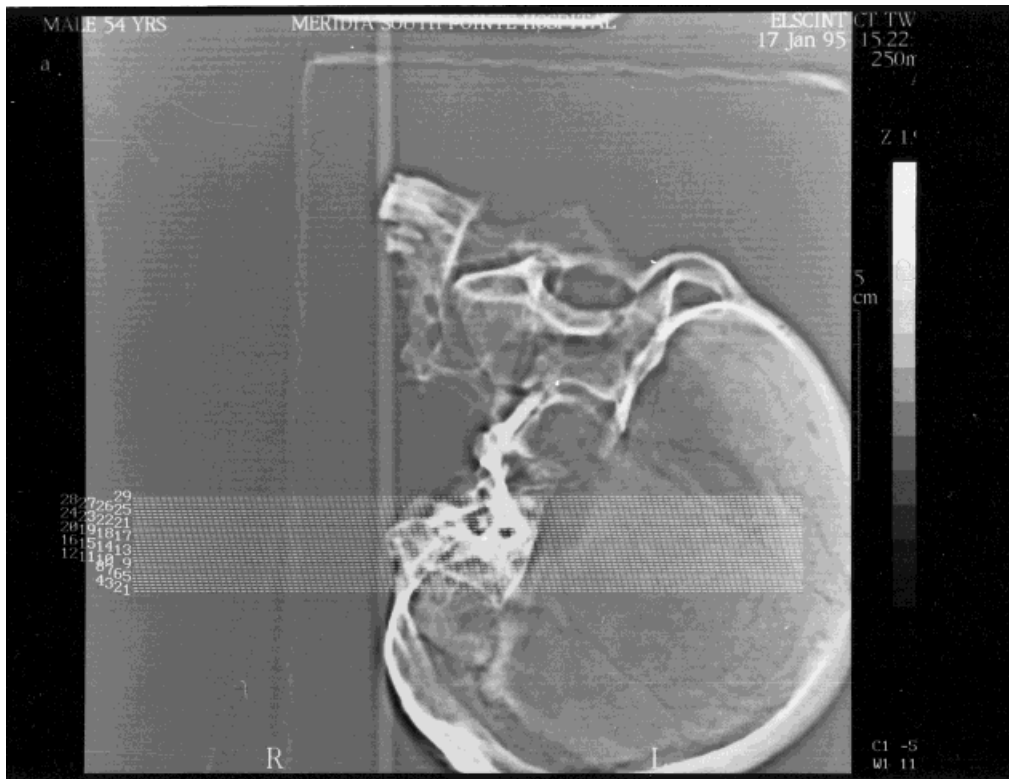


Fig. 6. Area of scanning.

variance showed no evidence ($P > .05$) for a significant variance component due to inter- and intraobserver error. When variance components were expressed as percentages of the sum of their variances, the following results were obtained: intraobserver = 2.25%; interobserver = 4.23%.

DISCUSSION

The following three questions have been addressed: 1) Do anatomical textbooks contain inadequate information regarding closure of the petroexoccipital articulation (jugular synchondrosis)? 2) Should these texts make changes with reference to the time of fusion? 3) Can closure status of the jugular synchondrosis improve our methodologies for estimating age? It is our assertion that these questions should all be answered in the affirmative.

Anatomical perspective

Some clarification is needed to disperse the ambiguity regarding the nature of the petrooccipital articulation. Although it is usually referred to as one anatomical unit (petrooccipital suture), the petrous bone articulates with the occipital bone in three different areas: the basioccipital region, the jugular process, and the supraoccipital region (Fig. 1). Based on Gray's Anatomy (Williams and Warwick, 1980) and Anatomy of the Infant Head (Bosma, 1986), the first articulation (petrobasioccipital) is mainly cartilaginous in nature; the second (petroexoccipital) has a cartilaginous growth plate, and, hence, should be classified as synchondrosis; and the third (petrosupraoccipital) composes the most inferior part of the occipitomastoid suture, and, hence, is sutural in nature.



Fig. 7. CT sections through the petroexoccipital articulation (HTH 1228) joint not fused (see arrowhead).

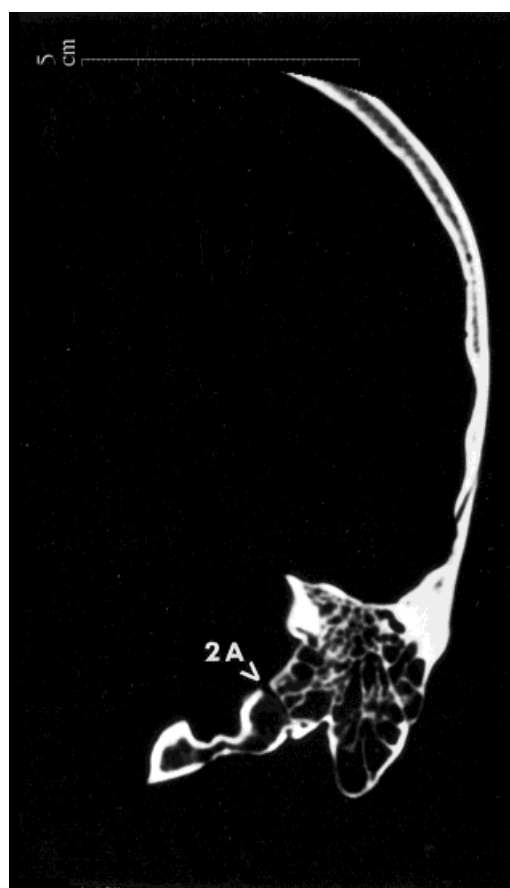


Fig. 8. CT sections through the petroexoccipital articulation (HTH 1118) joint fused (see arrowhead).

Classical anatomical texts, for example, Gray's Anatomy (Williams and Warwick, 1980), Cunningham Text-Book of Anatomy (Brash and Jamieson, 1937), and *Traité D'Anatomie Humaine* (Testut, 1911) refer only briefly to the petroexoccipital articulation and largely repeat themselves. Gray's Anatomy (Williams and Warwick, 1980) states that at "about the age of 25, this plate begins to ossify" (p. 322). To date, no one has seriously examined this question.

Our results indicate that we are not dealing with a process that transpires over several years but, rather, with a phenomenon (synchondrosis) that occurs over a relatively short period, independent of other cranial sutures, much like the closure of the sphenoccipital joint. Therefore, a more accurate

statement in the anatomical textbooks would be: "The petroexoccipital articulation (in previous editions called 'jugular synchondrosis') closes before the age of 20 years in 7–10% of the population and remains open in 5–9% of the population after the age of 60. In a majority of human skulls, however, the articulation undergoes closure between 20 and 50 years of age."

Anthropological perspective

The union of the jugular process with the petrous bone can be used as a simple criterion for age evaluation. Although it cannot predict precise chronological age, closure of the petroexoccipital articulation (jugular synchondrosis) can be used to assign an upper limit to the middle age group (middle age group = 25–40 years). If the joint does not

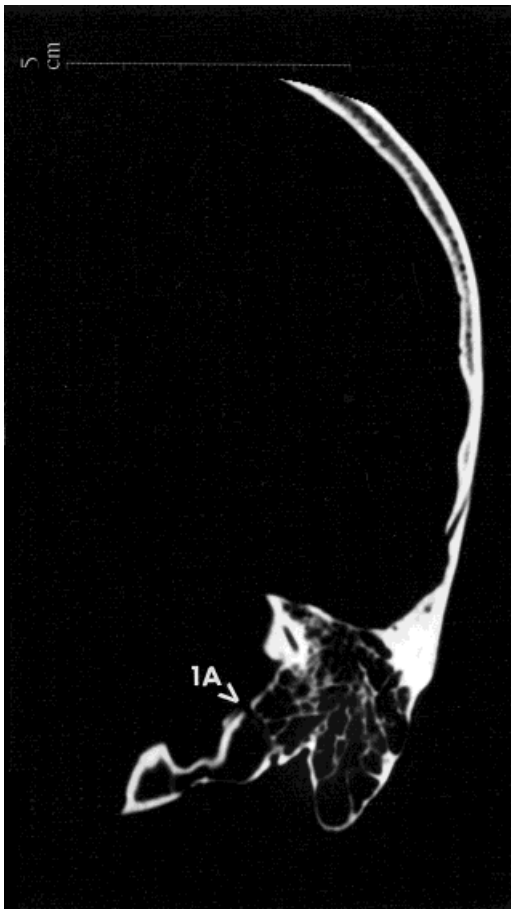


Fig. 9. CT sections through the petroexoccipital articulation (HTH 989) joint not fused.

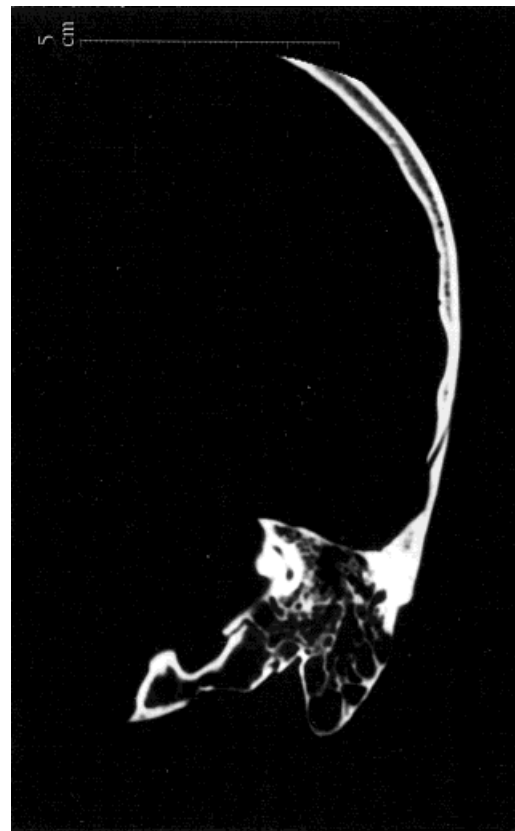


Fig. 10. Bony plate roofing the petroexoccipital articulation.

undergo closure, then the probability that the estimated age would be less than 20 years is ca. 95%. Although complete suture closure can be seen in very young individuals (ca. one-third of the individuals in the 20–25 age group), it is predominant in the older age group (more than 78% of all individuals above the age of 40 years). The chances of finding individuals above the age of 40 years with open petroexoccipital articulation (jugular synchondrosis) is less than 13%. It is worth noting that the “partial closed” status may be a permanent state rather than a transitional stage prior to closure. This would explain the constant percentage of crania in all age groups that manifest this condition.

TABLE 1. Frequency (%) of the right petroexoccipital articulation state by age group: Gender and ethnic origin combined

Age group	Closed	Open	Partial	N
20–25	32.6	60.4	6.9	144
30–35	58.8	23.7	17.5	245
40–45	78.0	13.7	8.2	378
50–55	84.6	8.1	7.3	383
60–65	87.8	7.6	4.6	287
70+	87.0	8.2	4.7	258

Considering the large age span, many anthropologists might disregard the importance of the petroexoccipital articulation (jugular synchondrosis) in cranial age estimation. However, there are very few age markers in the skull for the upper border of the middle age group, and this method provides at least some boundaries. This method makes use of a single criterion that does not necessitate a well-preserved skull or skel-

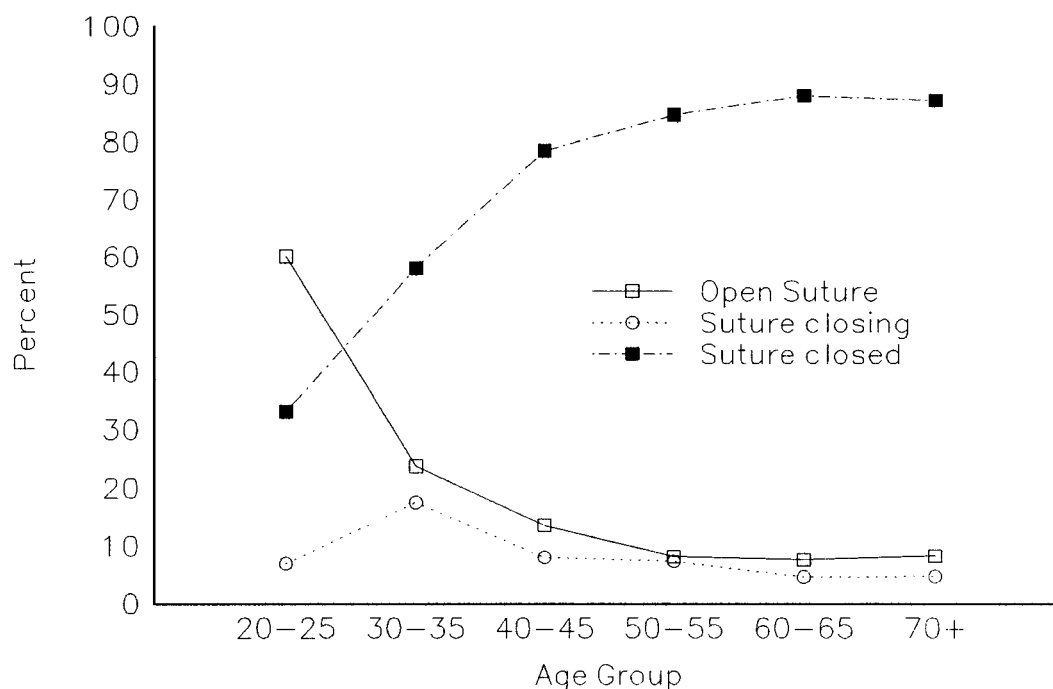


Fig. 11. Distribution of closure/open by age groups at 5-year intervals.

TABLE 2. Effect of gender and ethnic origin on closure time of the petroexoccipital articulation: Statistical analysis

Age group	Male vs. female		Afro-American vs. European-American	
	Chi square*	P value	Chi square*	P value
20-25	5.603	.0607	1.237	.5387
30-35	0.371	.8307	6.668	.0356
40-45	1.944	.3784	0.268	.8747
50-55	3.281	.1939	2.120	.3464
60-65	1.968	.3739	0.154	.9257
70+	0.201	.9043	3.629	.1629

*df = 2.

eton, as do most methods; is not contingent upon laterality, gender or ethnicity; and it utilizes one of the better preserved parts of the skull. Sometimes, all that remains of an individual is the petrous portion of the temporal bone. With this method, an estimate of age at death can be obtained. The fact that the inner part of the skull is used should not normally be a major obstacle, because, in many forensic/archaeological cases, the skull is fractured. When complete skulls are present, radiographs or CT scans can provide

the necessary data. Alternatively, the lateral wall of the jugular foramen can be observed from the outside. The method is highly reliable and easy to use, with minor inter- and intraobserver error. Comparative radiographs indicate high agreement with the naked-eye observation.

Maat and Mastwijk (1995) present results on the time fusion of the jugular growth plate that are contradictory to this study. It was therefore decided to present these results and discuss possible explanations for the discrepancies between the two studies. Maat and Mastwijk (1995) claim that "... no fusions were seen before the age of 22 years ... at ages above 34 years in female and above 36 years in males all jugular growth plates were fused bilaterally" (p. 163). They relate to the possibility that other skeletal series might show different data regarding the time-closure sequence of the jugular growth plate, attributing it to genetic differences among populations and/or secular trend shifts in maturation due to changing socioeconomic conditions within one population. Although these two factors might play

some role in jugular synchondrosis, the contradicting results of the two studies derive primarily from the nature of the samples used. Although 98 individuals constitute a fair sample (at least for anthropological studies), we may note from Figure 5 (a table with an age at death distribution is not supplied) that the age group under 20 years included only two individuals, and, between 20 and 25 years, only four individuals were present. With such a small sample, it is not surprising that "... no fusions were seen before the age of 22 years." To a lesser degree, this also applies to their second statement regarding total bilateral fusion after 36 years of age. The critical age group of 30–40 years is represented by only ten individuals. The sample size in all age groups beyond 40 years (at 10-year intervals) varies from 12 to 18 individuals.

Under the circumstances, a familiar warning must be restated: Phenomena in skeletal biology (i.e., suture closure, discrete traits, growth, etc.) should be approached only from a population perspective. Failing to meet this criterion will lead to a distorted, inaccurate picture.

The behavior of the petroexoccipital articulation differs completely from the sphenooccipital articulation. Whereas the later synostoses in a very short, fixed period (18–25 years), the former manifests a different pattern of synostosis, spreading over a prolonged time frame (occurring in individuals ranging in age from 16 to 60 years). Moreover, unlike the sphenooccipital articulation, the petroexoccipital articulation in 5–9% of the population does not undergo closure. The usefulness of the petroexoccipital articulation (jugular synchondrosis) in forensic and paleodemographic work depends largely on the material available. The open condition can be used to determine an upper border age (50 years with 10% chance of error, 40 years with 15% chance of error, below 35 years of age with 25% chance of error). The closed condition can be used to place a lower limit (of 20 years) on the adult age group (with 7–10% chance of error). For the age group 20–25 years, the error increased to 33%.

This paper does not allege to solve the problem of aging based on the skull alone, nor does it attempt to replace other methodologies. It merely suggests an additional tool that can be applied under certain circumstances (i.e., when only a fragmented skull(s) is available, and other methods are inapplicable) in forensic or anthropological cases.

ACKNOWLEDGMENTS

The authors are grateful to D. Ortner, The Smithsonian Institution Natural History Museum. This research was carried out during the sabbatical of the senior author (I.H.) at the Cleveland Museum of Natural History. It is part of a collaborative research project entitled "Dynamic Pattern in Human Skeletal Biology" between the Laboratoire d'Anthropologie Biologique, Faculté de Médecine de Marseille, Université de la Méditerranée, France; the Department of Physical Anthropology, Cleveland Museum of Natural History and Department of Anatomy, Case Western University, Cleveland, Ohio; and the Department of Anatomy and Anthropology, Sackler Faculty of Medicine, Tel Aviv University, Israel. We thank the photographer of the Cleveland Museum of Natural History, Mr. D. Flocke. The CT scans were carried out at the Meridia Suburban Hospital, Cleveland, Ohio. We are very grateful to Ms. Tia Trivison from Meridia Suburban Hospital for her help.

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